Effect of Scale on Tube Plate Temperature

Background

The recent three-yearly statutory inspection of a gas-fired shell boiler found extensive furnace-end cracks, tube-end cracks at the inlet to the first tube pass and very serious scaling on the water-side, as shown in figures 1 & 2. The scale was found to have a very high silica content the insulation properties of which significantly inhibit heat transfer, as described in paragraph D.2.6. A metallurgical investigation found that the furnace-end and tube-end cracking was due to thermal overload of the steel, for which the primary cause was found to be inadequate water treatment.

Fig 1 - Scale build-up on tube to tube plate

Fig 2 - Scale build-up on furnace to tube plate

Boiler Operation

The majority of shell boilers operating in South Africa at present were designed in accordance with the design code BS2790. In Appendix D – Boiler Operation, it states the following:

D.2.5. Deposits. Impurities introduced into the boiler with feed water can produce scale or other deposits which impede the transfer of heat and may restrict the flow of water. In addition to reducing boiler efficiency, either effect leads to insufficient cooling of the metal heat transfer surface which may then become so hot that it is no longer strong enough to withstand the operating pressure. Deposits may also lead to corrosion by shielding the underlying metal from protective conditions in the water or steam.

D.2.6. Scale. Calcium, magnesium and silicon compounds are the main constituents and can form scales of widely differing characteristics with thermal conductivities varying from 216 to 3450 W.mm/(m^2.K). In practice this means that some silicon based scales of only 0.1 mm thickness can impede the transfer of heat as effectively as a calcium sulphate scale 1.6 mm thick.

It is therefore important that any scale build-up is detected as soon as possible. It is essential that the cause also be investigated and corrected as in many cases it is not possible to determine the composition of the scale without chemical analysis. Some silicon-based scales are almost invisible to the naked eye and are detected more easily by the use of a special instrument.

D.3.1 Overheating in a boiler can be caused by the accumulation of scale and internal deposits. The following damage can result.
a) Collapse or deformation of the furnace
b) Collapse or deformation of the reversal chamber
c) Hogging or sagging of smoke tubes
d) Leaking from tube expansions
e) Cracking of welds and of tube ends at the tube plate attachments
f) Bulging of tube plates and cracking of ligaments

Boiler Design

The reversal chamber tube plate of a fire-tube shell boiler is designed for optimum heat transfer in accordance with the boiler design code. In the latest code, BS EN12953:2002, which has superseded BS2790, the maximum allowable hot-face metal temperature is 420 deg C. However, should abnormal situations occur such as over-firing or build up of internal (waterside) scale, excess heat accumulates on the metal surface. Scale acts as an insulator and inhibits heat transfer from the metal to the water and consequently this results in heat build-up on the tube-end and furnace-end inside corner tip as indicated in Fig 3.

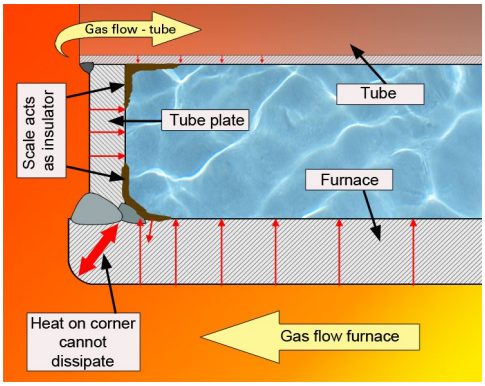

Fig 3 – Simplified schematic of heat transfer at end of furnace and tube

The insulation properties of different types of scale are indicated in Fig 4. Design calculations for a boiler with no scale and operating at full load and 1 500 kPa show that the tube plate hot-face metal temperature with natural gas is 389°C, but with 0.1 mm silicon based scale this temperature will exceed 550°C. The tube end will be higher. As the metal temperature increases the tensile and yield strengths decrease. They reach a point where they can no longer sustain the inherent structural stresses and micro cracks appear at the corner tip. These cracks are very distinctive. With each repeated cycle they propagate further, filling with oxidation product. Ultimately the cracks will run through the tube wall and weld, into the tube plate resulting in serious damage to the boiler

To prevent thermal fatigue due to scale it is essential that water quality is maintained in accordance with BS EN12953-10:2003 Shell Boilers - Requirements for feed water and boiler water quality.

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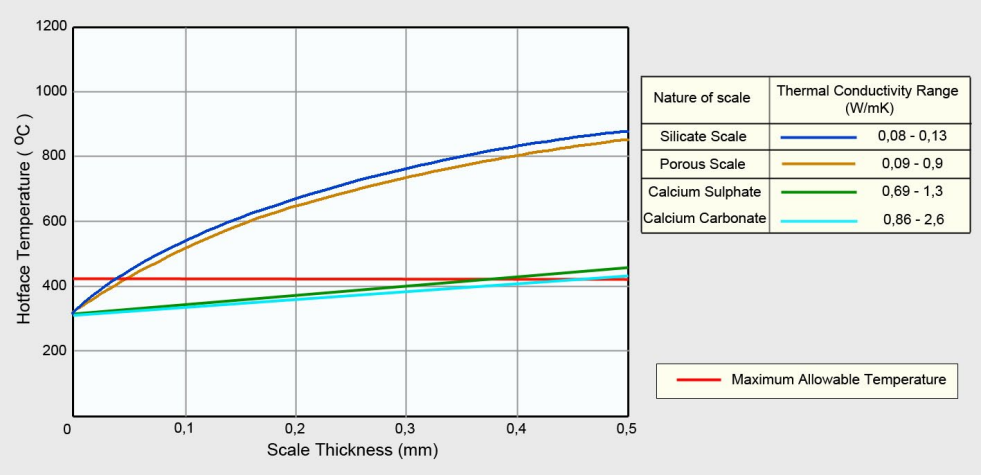
Fig 4 – Effect of scale on tube plate temperature



JOHN THOMPSON. A division of ACTOM (Pty) Ltd

Cape Town Head Office — PO Box 129, Bellville, RSA — Tel:+27(0)21 959-8400 — Fax:+27(0)21 959-8545
Johannesburg Office — PO Box 8382, Edenglen, RSA — Tel:+27 (0)11 392-0900 — Fax:+27 (0)11 392-0938
Durban Office — PO Box 32292, Mobeni, RSA — Tel:+27 (0)31 408-9700 — Fax:+27 (0)31 408-9722

www.johnthompson.co.za e-mail:info@johnthompson.co.za